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Prediction and Optimization of End milling process parameters of LM24 Aluminium alloy based MMC

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***Abstract*— Metal matrix composites (MMCs) have been widely used in industries and these materials are difficult-to-machine because of the hardness and abrasive nature of reinforcement material. Aluminium matrix composites (AMCs) are emerging as advance engineering materials due to their strength, ductility and toughness. The present study investigate the effect of spindle speed, feed rate, depth of cut and different percentage (% wt.) of Al_2O_3 on surface roughness in end milling of LM24 Al alloy. LM24 Al alloy is reinforced with various composition (weight %) of Alumina using Stir casting method. Stir casting is employed to prepare the specimen because of better and even spread of reinforcement material. Experiments is conducted on a CNC end milling machine according to the principles of Response surface methodology design of experiments (DoE) method. . A predictive response surface model for surface roughness is developed using RSM. Optimal combination of these parameters can be used to achieve the minimum surface roughness.**

***Index Terms*— Metal matrix composites, Response surface Methodology, Surface roughness**

I. INTRODUCTION

Metal Matrix composites are new class of material that are being used to replace conventional materials. The reinforcement material such as silicon carbide, aluminium oxide or alumina, boron carbide etc. can be added to aluminium to enhance its property. These Metal Matrix composite material finds application in various engineering applications like aerospace and automobile industries.

R. AROKIADASS et al [1] developed a model to predict the tool wear while machining of LM25 Al alloy reinforced with SiC_p particles using the process parameters of spindle speed, feed rate, depth of cut and % of SiC_p. BASHEER et al [2] developed a model to predict the surface roughness in precise machining of metal matrix composites considering the size and volume of reinforcement, tool nose radius, feed rate, and the depth of cut. PALANIKUMAR and DAVIM [3] developed a model to assess the factors that areinfluencing tool wear on the machining of glass fibre-reinforced plastics composites while machining with coated cement carbide tools using the analysis of variance. TAMER OZBEN et al. [4] investigated the effects of machining parameters on tool wear and surface roughness of aluminium MMC reinforced with silicon carbide particulate (SiC_p) of different volume fraction. ALAUDDIN et al. [5] developed a mathematical model to predict the surface roughness of 190 BHN steel in end milling process with cutting speed, feed rate and depth of cut as parameters. The response surface methodology was used to find the effect of these parameters on surface roughness.

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II. EXPERIMENT

In the present experimental study, the material to be machined was LM24 Al alloy reinforced with Al_2O_3 particles. The composition is 3%, 6%, 6%, 12% and 15% (mass fraction). The machining were performed on CNC end milling machine. The dimensions of the specimens were 100 mm× 10 mm × 10 mm. The composition of the LM24 Al alloy specimen is presented in Table I. The cutting tool used was Nano crystal coated carbide tool cutter, having diameter of 5 mm, helix angle of 45°.

TABLE I. Chemical composition of LM24 aluminium alloy (mass fraction, %)

Cu	Mg	Si	Fe	Mn	Ni	Zn	Pb	Sn	Ti
3	0.3	7.5	1.3	0.5	0.5	3	0.3	0.2	0.2

III. DESIGN OF EXPERIMENTS

The experimental parameters are listed in Table II. In this study, the spindle speed (A), feed rate (B), depth of cut (C) and % wt. of Al_2O_3 (D) are taken as process parameters. The surface roughness is obtained through a series of experiments based on central composite rotatable design, as shown in Table III, to develop the equations of the response surface. Design of experiment (DoE) features of MINITAB-17 software were utilized to obtain the central composite rotatable design and also to determine the coefficients of mathematical modelling based on the response surface regression model.

TABLE II. Experimental parameters and their levels

No.	Factor	Unit	Notation	Level				
				-2	-1	0	1	2
1	Spindle speed	RPM	N	2000	2500	3000	3500	4000
2	Feed rate	mm/rev	f	0.02	0.03	0.04	0.05	0.06
3	Depth of cut	mm	d	0.5	1	0.5	2	2.5
4	Al_2O_3	% wt.	A	3	6	9	12	15

The mathematical relationship, obtained for analysing the influences of the various dominant process parameters on the surface roughness is given by:

R_a = 0.24857 – (0.01750 A) + (0.04167 B) + (0.00417 C) + (0.01583 D) + (0.00473 A^2) + (0.00723 B^2)

+ (0.00098 C^2) – (0.00152 D^2) – (0.00250 A*B)
– (0.00000 A*C) + (0.00250 A*D) – (0.00125 B*C)
+ (0.00125 B*D) + (0.00375 C*D) (1)

Equation (1) is the regression equation. Where R_a is surface roughness and A, B, C, and D represent the decoded values of spindle speed (N), feed rate (f), depth of cut (d), and %wt. of Al_2O_3 (A), respectively. The developed mathematical model can be used to analyse the effects of process parameters on surface roughness (R_a).

TABLE III. Experimental design matrix and results

Ex. No.	Control factors				Surface roughness (R_a)	Predicted Value
	A	B	C	D		
1	-1	-1	-1	-1	0.22	0.21957
2	1	-1	-1	-1	0.19	0.18457
3	-1	1	-1	-1	0.3	0.30791
4	1	1	-1	-1	0.26	0.26291
5	-1	-1	1	-1	0.23	0.22291
6	1	-1	1	-1	0.18	0.18791
7	-1	1	1	-1	0.3	0.30625
8	1	1	1	-1	0.27	0.26125
9	-1	-1	-1	1	0.23	0.23623
10	1	-1	-1	1	0.21	0.21123
11	-1	1	-1	1	0.33	0.32957
12	1	1	-1	1	0.29	0.29457
13	-1	-1	1	1	0.25	0.25457
14	1	-1	1	1	0.24	0.22957
15	-1	1	1	1	0.34	0.34291
16	1	1	1	1	0.3	0.30791
17	-2	0	0	0	0.31	0.30249
18	2	0	0	0	0.23	0.23249
19	0	-2	0	0	0.19	0.19415
20	0	2	0	0	0.37	0.36083
21	0	0	-2	0	0.25	0.24415
22	0	0	2	0	0.26	0.26083
23	0	0	0	-2	0.21	0.21083
24	0	0	0	2	0.28	0.27415
25	0	0	0	0	0.25	0.24857
26	0	0	0	0	0.24	0.24857
27	0	0	0	0	0.26	0.24857
28	0	0	0	0	0.25	0.24857
29	0	0	0	0	0.23	0.24857
30	0	0	0	0	0.25	0.24857
31	0	0	0	0	0.26	0.24857

The value of the coefficient was calculated by using Minitab Software. The significance of each coefficient was determined by Student's t test and p values, which are listed in Table IV. The values of p less than 0.05 indicate that the model terms are significant. The values greater than 0.10 indicate that the model terms are not significant.

The fit summary recommended that the quadratic model is statistically significant for analysis of surface roughness. The results of quadratic model for surface roughness are shown in Table IV. The value of R^2 for surface roughness is 97.46%, which means that the regression model provides an excellent explanation of the relationship between the independent variables (parameters) and the response (R_a).

Table IV. Regression analysis of surface roughness (R_a)

Term	Coefficient	P value
Constant	0.24857	<0.000
A	-0.01750	<0.000
B	0.04167	<0.000
C	0.00417	<0.052
D	0.01583	<0.000
A^2	0.00473	<0.019
B^2	0.00723	<0.001
C^2	0.00098	0.596
D^2	-0.00152	0.416
A*B	-0.00250	0.319
A*C	-0.00000	1.000
A*D	0.00250	0.319
B*C	-0.00125	0.614
B*D	0.00125	0.614
C*D	0.00375	0.142

The p value for the model is less than 0.05 (i.e., p=0.05 or 95% confidence), which indicates that the model is statistically significant. From the Table V, the p values of regression analysis of surface roughness indicates that linear effect of spindle speed, feed rate and percentage weight of Al_2O_3 are significant. In square terms, spindle speed, feed rate and percentage weight of Al_2O_3 are significant. In interaction terms, spindle speed, feed rate and feed rate, %wt. Al_2O_3 are significant. The standard percentage point of F distribution for 95% confidence limit is 4.06. As shown in Table IV, the F value (0.72) for lack of fit is smaller than the standard value. Thus, the model is adequate. It is also seen that from the p values, for surface roughness the linear, square and interaction effects are significant.

Table V. Analysis of variance for surface roughness (R_a)

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-value	p-value
Regression	14	0.058083	0.004149	43.94	0.000
Linear	4	0.055450	0.013863	146.82	0.000
Square	4	0.002158	0.000539	5.71	0.005
Interaction	6	0.000475	0.000079	0.84	0.558
Residual Error	16	0.001511	0.000094		
Lack of fit	10	0.000825	0.000083	0.72	0.691
Pure Error	6	0.000686	0.000114		
Total	30	0.059594			

IV. RESULTS AND DISCUSSION

A mathematical model was developed to predict the surface roughness by relating it with process parameters such as spindle speed, feed rate, depth of cut and depth of cut. The direct and the interaction effects of these process parameters on surface roughness were calculated plotted are shown in figs. and the cause and effect were analysed.

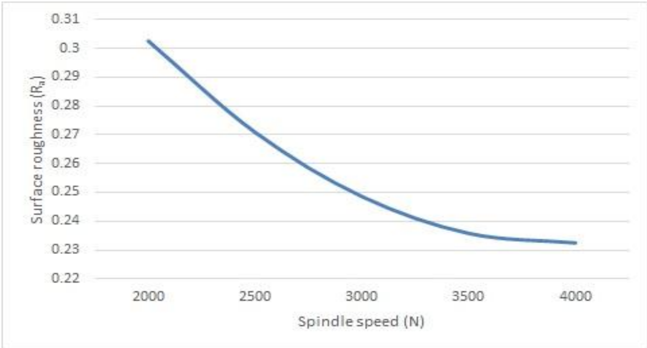

Fig 1. Direct effect of spindle speed

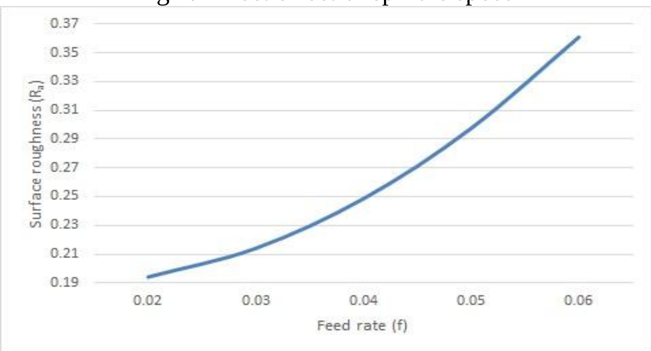

Fig 2. Direct effect of feed rate

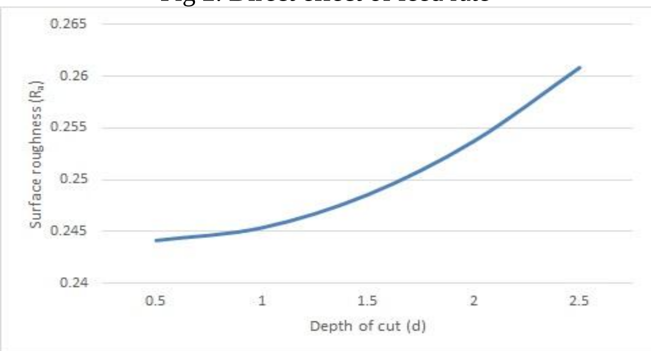

Fig 3. Direct effect of depth of cut

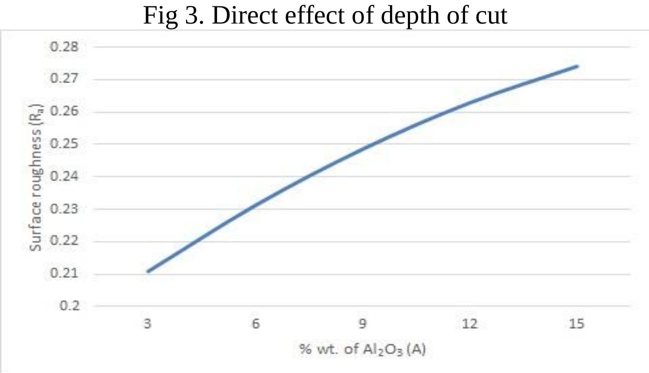

Fig 4. Direct effect of %wt. of Al_2O_3

The direct effect of spindle speed, feed rate, depth of cut and %wt. of Al_2O_3 were experimentally investigated. From Fig1, increase in the spindle speed reduces surface roughness (R_a). This is because at high speed built-up-edge formation will not occur which reduces the surface roughness. From Fig 2, increase in feed rate increases the surface roughness which is due to the generation of heat and chatter during machining. rom Fig 3, increase in depth of cut increases the surface roughness. From Fig 4, increase in %wt. of Al_2O_3 increases the surface roughness. This is because when there is increase in %wt. of Al_2O_3 the hardness of the material increases.

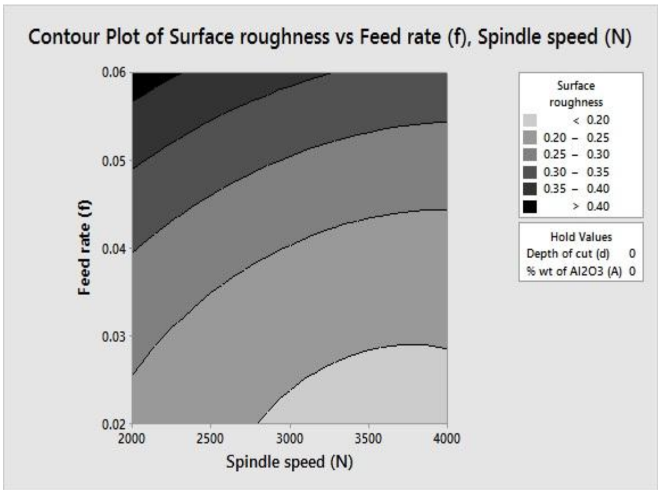

Fig 5. Effect of spindle speed (N) and feed rate (f) on surface roughness (R_a)

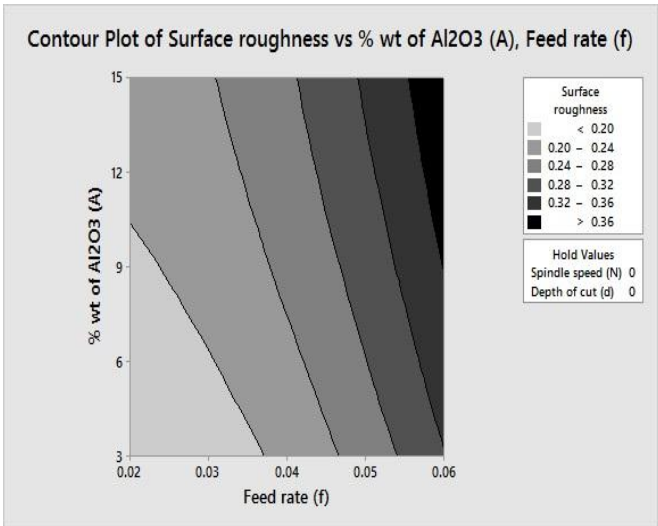

Fig 6. Effect of feed rate (f) and %wt. of Al_2O_3 (A) on surface roughness (R_a)

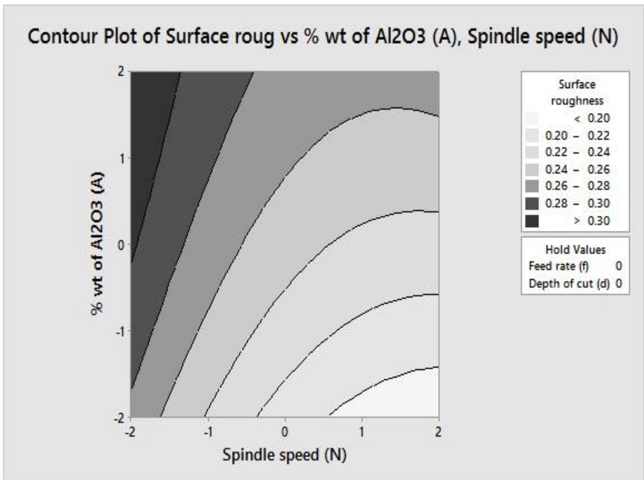

Fig 7. Effect of spindle speed (N) and %wt. of Al_2O_3 (A) on surface roughness (R_a)

Strong interaction between the process parameters was observed for surface roughness. Fig 5 shows the interaction effect of spindle speed and feed rate. Increase in the spindle speed decreases the surface roughness. At low spindle speed formation of BUE occurs and also the chips fracture will cause the surface roughness. As the spindle speed increases, the BUE vanishes, chip fracture decreases and hence, the surface roughness decreases. Also minimum surface roughness, were obtained at the lowest level of feed rate. The reason being, the increase in feed increases the heat generation and hence, tool wears, which results in higher surface roughness. The increase in feed also increases the chatter, and it produces incomplete machining of work piece, which led to higher surface roughness. The best surface finish was achieved at the lowest feed rate and highest spindle speed combination. Fig 6 shows that the interaction effect of feed rate and %wt. of Al_2O_3. The surface roughness (R_a) decreases as the feed rate (f) decreases. But the surface roughness (R_a) increases with the increase in %wt. of Al_2O_3 (A). The reason is that addition of reinforcing materials makes the material harder, machining becomes more difficult. The best surface finish was achieved at the lowest feed rate and lowest %wt. of Al_2O_3 combination. Fig 7 shows that the interaction effect of spindle speed and %wt. of Al_2O_3. The surface roughness (R_a) decreases as the spindle speed increases. But the surface roughness (R_a) decreases with the decrease in %wt. of Al_2O_3.

V. CONCLUSION

The following conclusions were derived from machining LM24 Al alloy reinforced with Al_2O_3,

The mathematical model and empirical relationship was developed to predict the surface roughness of metal matrix composite is at 95 percent confidence level. Response surface methodology is used to develop the mathematical model to predict the surface roughness. From the experiment and evaluation it is observed the spindle speed, feed rate and %wt. of Al_2O_3 has main effect on surface roughness. The surface roughness is better at high speed and low depth of cut.

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